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Initial selection and breeding of *Lesquerella fendleri*, a new industrial oilseed

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Abstract

Considerable research and developmental efforts are being devoted by both the public and private sectors to commercialize *Lesquerella fendleri* as a new industrial oilseed crop for the production of hydroxy fatty acids. Selection and breeding research initiated in 1984 at the USDA-ARS, US Water Conservation Laboratory, Phoenix, Arizona has made progress in increasing seed, oil and lesquerolic acid yields. Yields of 1700 kg/ha of seed, 30% oil and 59% lesquerolic acid have been obtained in replicated trials. Single plant selections developed during the interim are traceable to two populations: one to a single collection made in Arizona, PI 331165, and the other to nine different accessions collected from various sites in Texas. Variation among selections within each population exhibited relatively the same amount of genetic variability. Neither population appeared to be superior as a source of variation. The need for acquisition and utilization of new sources of germplasm is indicated. Topcross yield performance of six selected lines appeared to be superior to that of comparable half-sib family progeny, validating the existence of heterosis, which is expected due to the high degree of natural cross pollination observed. These data should serve as a benchmark upon which future progress in varietal and population development can be measured.

Selection; Breeding; Oilseed; *Lesquerella*; Hydroxy fatty acid

Introduction

Public and private sector attention is centered on the domestication and commercialization of *Lesquerella fendleri* as a new industrial oilseed for the production of hydroxy fatty acids. A thorough assessment of the potential of lesquerella production and utilization was published recently by the USDA Office of Agricultural Materials (Roetheli et al., 1991).

Castor oil, which is utilized in the manufacture of a wide array of products including high performance lubricants, corrosion inhibitors, coatings, plastics, nylons, resins, waxes, cosmetics and pharmaceuticals, is currently the only source of hydroxy fatty acids. The United States and other industrialized countries in Europe and Asia are totally dependent upon importations of castor oil, chiefly from China, India, Thailand and Brazil.

It is envisioned that use of lesquerella oil as a new hydroxy fatty acid source will complement that of castor oil. Lesquerella oil should be able to replace castor oil in some current industrial applications. Moreover, the longer carbon chain length (C20 for lesquerolic acid vs. C18 for ricinoleic acid) should provide an opportunity for developing unique applications and products.

In 1984, research was initiated at the USDA-ARS, US Water Conservation Laboratory (USWCL), Phoenix, Arizona to evaluate germplasm and determine the feasibility of domesticating lesquerella as a new industrial oilseed crop.

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The species *Lesquerella fendleri* (Gray) Wats. (Brassicaceae) was identified as the most promising for rapid domestication and ultimate commercialization (Thompson, 1985, 1988). Initial results on selection and breeding for agronomic characters and improved yield have been summarized (Dierig and Thompson, 1993; Dierig et al., 1992; Senft, 1992; Thompson, 1988, 1990a,b; Thompson and Dierig, 1988; and Thompson et al., 1989, 1992).

Research on the extraction and utilization of seed oil and meal is also in progress at the USDA-ARS, National Center for Agricultural Utilization Research (NCAUR), Peoria, Illinois (Carlson et al., 1990a,b; Roetheli et al., 1991; R. Kleiman, personal communication, 1993). In addition, cooperative feeding trials of lesquerella seed meal are being conducted on beef cattle at the University of Arizona, Tucson, and on chicks and rats at Kansas State University, Manhattan to evaluate its nutritional value.

Agronomic research is being conducted at the USWCL, in cooperation with the University of Arizona at the Maricopa Agricultural Center (MAC) to develop an efficient and profitable crop production and harvesting system. Research is also being done cooperatively with scientists at Texas A&M University, Fort Stockton, Texas; Oregon State University, Corvallis and Medford, Oregon; Virginia State University, Petersburg, Virginia; and two industrial companies, Agrigenetics L.P., a subsidiary of Mycogen Corporation, San Diego, California, and International Flora Technologies, Ltd., Apache Junction, Arizona. Financial support for this commercialization effort is also being provided by the USDA-CSRS, Office of Agricultural Materials.

An extensive effort by USDA-ARS is underway in Arizona to collect and evaluate new germplasm, and to select and breed varieties or populations with high seed, seed oil and lesquerolic acid yields. The objective of this paper is to describe and characterize the selection and breeding efforts to date. This information should serve as the base upon which future genetic advance can be measured.

Materials and Methods

Sources of *Lesquerella fendleri* germplasm and relationships among single plant selections (SPS), half-sib families (HSF), half-sib family progeny (HSFP), topcross progeny (TCP) and populations developed during the initial phase of the selection and breeding program from 1984 to 1991, are detailed in Fig. 1.

Initial breeding efforts involved the evaluation of variation within and among 24 accessions of *Lesquerella fendleri* in the USDA-ARS working germplasm collection at the USWCL. Seeds of these accessions were planted in non-replicated plots at MAC in central Arizona on 1 October, 1984. A total of 56 single plant selections from 18 accessions were made in early March, and hand harvested on 20 June, 1985. Details of cultural methods and yield performance of 39 half-sib families from these intitial selections were reported by Thompson et al. (1989). The number of entries was reduced to 35 for consideration in this paper since four of the single plant selections had insufficient remnant seed for oil and fatty acid analysis. This first series of 35 selections, which originated from three seed sources, is referred to as the '1986 Population' (Fig. 1).

A second series of selections from *L. fendleri* (referred to as the '1988 Population') was derived in part from germplasm obtained in 1984 from Dr. D.D. Rubis, who conducted germplasm evaluation and selection within species of *Lesquerella* from 1966–1978 at the University of Arizona, Tucson. Details of this effort are summarized in unpublished annual reports of the Arizona Agricultural Experiment Station, which were not obtained by the authors until November, 1990. Of the 57 accessions received, 20 were *L. fendleri*, 26 were *L. gordonii*, and 11 were from 10 other species of *Lesquerella*. Except for 12 accessions of *L. gordonii* collected by Dr. Rubis in Arizona, all the germplasm had the same origin as that of the USDA-ARS working germplasm collection assembled at the USWCL from other sources.

In addition, seeds of a series of 285 single plant selections of *L. fendleri* made by Dr. Rubis in 1977 from some 201 half-sib family rows (presumably from single plant selections made in 1976) were also obtained. The selection criteria for the 285 selections are unknown, but presumably were for erect-growing, nonshattering, high-yielding plants. Apparently none of the selections had been evaluated for seed oil or fatty acid content. About 20 kg of a bulk lot of 1975 seed were also obtained

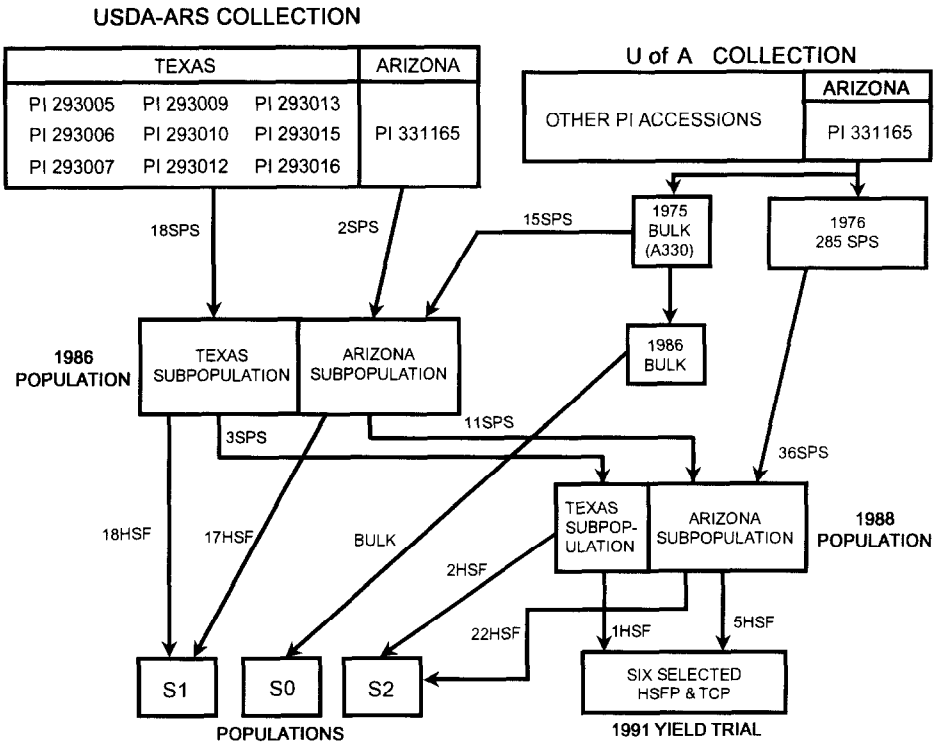

Fig. 1 Source of *Lesquerella fendleri* germplasm and relationships among single plant selections (SPS), half-sib families (HSF), half-sib family progeny (HSFP), topcross progeny (TCP) and populations in the USDA-ARS Lesquerella Selection and Breeding Program – 1984–1991.

and given an accession number (A330). Seeds from this bulk lot were planted in 1985, from which 15 single plant selections were made. These 15 selections constituted about half of the selections evaluated in the 1986 Population (Fig. 1).

After their receipt in 1990, the unpublished reports of Dr. Rubis were studied to determine the original source of the 285 selections and the bulk population we designated as A330. Surprisingly, all of the 285 selections and the bulk population (A330) appear to have been derived from only one accession: PI 331165. This collection was made in 1968 by Dr. A.S. Barclay near Bylas, Arizona, about 65 miles east of Phoenix. The first mention of its evaluation was made by Dr. Rubis in 1969. In a performance trial, it yielded about 1020 kg seed/ha, which exceeded the mean yield of three other accessions by 16%. In 1971, he reported that this accession had good seed yield and the seeds were relatively nondormant. No information is available for 1972 or 1973. Reports from 1974 through 1977 indicate that most of the experimentation concentrated on selections and bulk populations derived from PI 331165. Therefore, it is reasonable to conclude that most of the materials obtained from Dr. Rubis and grown as a part of both the 1986 and 1988 Populations originated from PI 331165. These selections and their half-sib progeny, which trace back to PI 331165, will be designated as Subpopulation AZ within the 1986 and 1988 Populations. Selections made from PI 331165, which was obtained previously from other sources and designated as A332 in the USDA Working Germplasm Collection at Phoenix, are also included in Subpopulation AZ.

Subpopulation TX within the 1986 and 1988 Populations consists of single plant selections and their half-sib progeny from nine different germplasm accessions collected by Dr. H.S. Gentry in 1961 at various locations in Texas. Dr. Rubis evaluated eight of these accessions in Tucson, Arizona in his 1967 report.

The progenies from the 285 single plant selections obtained from Dr. Rubis were not grown

out for evaluation until the 1987–88 growing season. At that time, 45 additional half-sib families from single plant selections made from the 1986 Population were also evaluated. Ten of these were from Subpopulation TX and 35 from Subpopulation AZ. Seeds of the 330 half-sib families were planted with a Planet Jr. seeder in rows 33 cm apart on 1 October, 1987 in a level basin irrigation border. The row length of individual, non-replicated plots varied from 3 to 45 m depending upon the amount of seed available. The seeding rate was adjusted to deliver about 100 seeds per meter of row length in an attempt to obtain plant populations of about 0.5 million per hectare. Plant establishment and subsequent irrigations were by sprinklers.

A total of 50 of the HSF plots grown in 1987–88 were selected on the basis of plant growth characteristics and seed yield. A majority of the HSF were derived from Subpopulation AZ; thirty-six from the 285 SPS, and 11 from the 1986 Population (Fig. 1). Only three of the 50 HSF came from SPS made within the TX subpopulation of the 1986 Population. Duplicate samples within plots were harvested on 7 June, 1988. In most instances, the plots were 5 m long or 1.67 square meters. Data were collected on plant population, plant height and total above ground dry biomass. Plots were threshed to obtain cleaned seed yield, 1000-seed weight and harvest index.

Oil and fatty acid content analyses of single plant selections and half-sib family progeny were made at the NCAUR with pulsed NMR, and conventional gas chromatography, respectively (R. Kleiman, personal communication, 1989).

After 1986, a total of three open-pollinated bulk seed populations, S0, S1 and S2, were created for use as seed stocks for agronomic and water use management research, and as a source for recurrent selection (Fig. 1). S0 consisted of bulk seed harvested in 1986 from plots planted with A330, which is the 1975 bulk seed population obtained from Dr. Rubis in 1984.

The S1 population was composed of progeny of the first series (1986 Population) of single plant selections. After the 1986 harvest, a 1986 Half-Sib Family Bulk was created by bulking about 500 g of seeds harvested from each of the 35 half-sib families. Ten kg of these seeds were mixed with 0.8 kg of a bulk of the 10 best half-sib families (86 Selected Bulk). To ensure adequate seed for planting, an additional 5 kg of combine-harvested seeds from a 1987–88 planting of the 1986 Half-Sib Family Bulk were also added to complete the S1 bulk population.

The S2 population was generated from an isolated crossing block containing 24 open-pollinated progeny from the highest yielding half-sib families grown and harvested in 1988. Twenty-two of these selections trace their ancestry back to Subpopulation AZ, which relate to PI 331165. Only two were derived from Subpopulation TX. The 24 lines were randomly distributed in eight replications within a 0.15 ha field. The crossing block was planted on 7 October, 1988, and about 200 kg of bulked clean seed were harvested by combine on 5 June, 1989.

Six of the highest yielding half-sib families from single plant selections evaluated during the 1987–88 growing season were selected for further study and controlled crossing. Five of the selections were from Subpopulation AZ and only one was from Subpopulation TX. Remnant seeds from the six single plant selections were grown separately in isolation in 1.8×3.0 m Saran plastic screened cages to produce half-sib family progeny seed. In addition, seeds from the six selections were randomly distributed in four replications within a larger 3×9 m screened cage to obtain topcrossed seed from each line. Cross pollination among plants within the cages was facilitated by nuclear units of honey bees.

During the 1990–91 growing season, the yields of the half-sib family progeny (HSFP) and their comparable topcross progeny (TCP) were evaluated in a randomized complete block design experiment with six replications. Plots of the S0, S1 and S2 populations were also included as checks. The planting was designed so that individual plots could be harvested with a conventional combine. The plots were planted with a Hege one-row, cone plot seeder, two rows per bed on 10 October, 1990. The plots were 3 m wide, consisting of three 1 m wide raised vegetable beds 18 m long. The seeding rate was 9 g per plot. Standard agronomic practices were followed, and the plots were harvested on 10 June, 1991. Since the plots were harvested with a combine, no data were taken on biomass, and consequently no estimates of harvest index were obtained.

Results and Discussion

Yield characteristics of the three bulk populations that have been used for crop and water management research, and as recurrent sources for single plant selection are compared in Table 1. The S1 population has significantly lower yield than either S0 or S2 in the 1991, replicated yield trial. Plant populations, which have a major influence on yield, were not significantly different among the three groups. Plant height in the S1 population was significantly shorter than in S0 and S2. Seed oil content was essentially the same for all three populations, but lesquerolic acid was significantly higher in S2. We have no explanation for the higher lesquerolic acid content since no deliberate selection for higher fatty acids had been made at the time these plants were selected. Early selections were primarily to improve plant height, vigor and seed yield. The significantly lower oil and fatty acid yields of S1 are largely related to the lower seed yield of this population.

The S0 population was derived from bulked seed of unselected, open pollinated plants of A330, which we have determined to have been derived from a single germplasm accession, PI 331165. This population exhibits considerable genetic diversity, which may be in part due to introgression with other accessions coexisting in Dr. Rubis' collection since 1969. However, based upon Dr. Rubis' reports, the majority of the breeding material in his plantings in 1973, or perhaps even 2 years earlier, were limited and traceable to PI 331165.

The S2 population is based in large part upon half-sib family progeny (HSFP) from high yielding single plant selections that trace back to A330 and other related material derived from PI 331165. Only two of the 24 selections were derived from two unrelated accessions originally collected in Texas.

The S1 population had a broader germplasm base since it was derived from the half-sib family progeny of 35 single plant selections from two geographical areas. Seventeen selections trace back to PI 331165 (Subpopulation AZ) that was originally collected in Arizona. The other 18 (Subpopulation TX) were selected from nine

TABLE 1

Yield characteristics of three *Lesquerella fendleri* bulk populations

Populations	Plant pop. (×1000)	Plant height (m)	Biomass dry weight (kg/ha)	Seed yield (kg/ha)	Harvest index (%)	1000-seed weight (g)	Seed oil		Lesquerolic acid	
							%	yield (kg/ha)	%	yield (kg/ha)
SO										
1986-Orig.	350	0.29	6896	1188	17.3	0.59	22.2	264	53.3	140
1989	1282	0.43	9999	1228	12.3	0.56	26.0	320	55.0	176
1990	700			812		0.58	28.6	233	50.3	117
1991	645[a]	0.43[a]		1506[a]		0.59[a]	29.0[a]	436[a]	57.6[b]	251[a]
Mean ($\bar{x}$)	744	0.38	8448	1184	14.8	0.58	26.5	313	54.0	171
SI										
1986-Orig.	626	0.35	7924	1260	15.9	0.58	26.0	328	53.1	174
1988	1234	0.41	7568	1056	14.0	0.50	25.9	274	52.9	145
1989	1411	0.44	8638	1191	13.8	0.49	26.3	313	54.6	171
1990	594			693		0.57	28.3	196	50.3	99
1991	532[a]	0.39[b]		1170[b]		0.58[a]	29.1[a]	340[b]	57.8[b]	196[b]
Mean ($\bar{x}$)	879	0.40	8043	1074	14.6	0.54	27.1	290	53.7	157
S2										
1988-Orig.	848	0.40	10345	1592	15.4	0.53	25.1	400	52.5	210
1990	509			725		0.58	28.6	207	51.3	106
1991	547[a]	0.46[a]		1515[a]		0.62[a]	28.9[a]	438[a]	60.6[a]	265[a]
Mean ($\bar{x}$)	635	0.43	10345	1277	15.4	0.58	27.5	348	54.8	193

[a]Mean separation in columns by Duncan's multiple range test, $P=0.05$.

TABLE 2

Yield performance of two sets of half-sib families of single plant selections derived from two original populations of *Lesquerella fendleri* collected in Texas (TX) and Arizona (AZ)

Yield measurements	1986 population				1988 population			
	Single plant selections		Half-sib families		Single plant selections		Half-sib families	
	TX($n=18$)	AZ($n=17$)	TX($n=18$)	AZ($n=17$)	TX($n=3$)	AZ($n=47$)	TX($n=3$)	AZ($n=47$)
Seed yield (kg/ha)								
Mean ± S.E.			1306 ± 67	1369 ± 52			1441 ± 253	1222 ± 49
Range			946–1740	888–1688			1066–1922	683–2044
C.V. (%)			21.6	15.8			30.4	27.4
t			0.74				0.85	
Biomass yield (kg/ha)								
Mean ± S.E.		6841 ± 415	8184 ± 340			9177 ± 888	8257 ± 291	
Range			4309–11172	5491–10250			7838–10856	4806–12772
C.V. (%)		25.8	17.1			16.8	24.1	
t			2.50*				0.99	
Harvest index (%)								
Mean ± S.E.			19.5 ± 0.6	17.0 ± 0.7			15.5 ± 1.2	14.9 ± 0.3
Range			15.1–23.7	11.7–22.7			13.6–17.7	8.8–18.5
C.V. (%)			13.9	16.3			13.4	13.2
t			2.71*				0.46	
1000-seed weight (g)								
Mean ± S.E.	0.61 ± 0.02	0.60 ± 0.03	0.62 ± 0.01	0.61 ± 0.01	0.65 ± 0.05	0.71 ± 0.02	0.51 ± 0.02	0.54 ± 0.01
Range	0.47–0.91	0.50–1.09	0.51–0.73	0.54–0.79	0.58–0.76	0.46–1.00	0.48–0.54	0.45–0.66
C.V. (%)	16.8	23.2	9.5	9.5	14.4	18.0	6.3	9.5
t	0.14		0.77		0.96		1.46	
Plant height (m)								
Mean ± S.E.			0.29 ± 0.01	0.34 ± 0.01			0.41 ± 0.01	0.38 ± 0.01
Range			0.21–0.38	0.24–0.39			0.38–0.44	0.32–0.45
C.V. (%)			14.1	10.3			6.2	9.0
t			3.99***				2.20*	

*,***Mean difference between populations measured by t-test (with 33 and 48 degrees of freedom for 1986 and 1988 populations) significant at $P=0.05$ and 0.001, respectively.

different PI accessions from various locations in Texas. It is not possible from these data to determine whether geographic location is a major factor contributing to the reduced yield of this population.

The geographical sources of the half-sib families within the 1986 and the 1988 Populations were examined to determine if they were a significant factor in the yield performance. Data sets of 35 single plant selections and their half-sib progeny in the 1986 Population and 50 selections and progeny in the 1988 Population were selected for comparison. The 1986 Population was nearly equally representated, with Subpopulation TX contributing 18 and Subpopulation AZ 17 selections and progeny. The 1988 Population was heavily skewed toward Subpopulation AZ with 47 entries, and only three from Subpopulation TX. Only data on seed oil and lesquerolic acid contents, and 1000-seed weights are available for the single plant selections. Data on seed yield, biomass yield, harvest index, plant height and seed oil and lesquerolic acid yields are available for all of the progenies.

Means, standard errors, ranges and coefficients of variation were calculated for each data set (Tables 2 and 3). The differences between the

TABLE 3

Oil and lesquerolic acid yield performance of two sets of half-sib families of single plant selections derived from two original populations of *Lesquerella fendleri* collected in Texas (TX) and Arizona (AZ)

Yield measurements	1986 population				1988 population			
	Single plant selections		Half-sib families		Single-plant selections		Half-sib families	
	TX($n=18$)	AZ($n=17$)	TX($n=18$)	AZ($n=17$)	TX($n=3$)	AZ($n=47$)	TX($n=3$)	AZ($n=47$)
Seed oil content (%)								
Mean ± S.E.	26.0 ± 0.7	25.6 ± 0.9	25.7 ± 0.3	26.4 ± 0.3	27.2 ± 0.6	24.4 ± 0.5	23.5 ± 1.7	25.5 ± 0.3
Range	21.7–33.4	17.4–34.3	22.2–28.4	23.3–28.6	26.1–28.3	16.5–30.5	21.0–26.8	21.6–29.6
C.V. (%)	11.7	14.5	5.6	5.0	4.0	14.6	12.8	7.8
t	0.39		1.98		3.43***		1.15	
Seed oil yield (kg/ha)								
Mean ± S.E.			338 ± 20	362 ± 16			345 ± 86	312 ± 13
Range			218–494	224–459			241–515	163–589
C.V. (%)			24.5	18.2			42.9	29.4
t			0.99				0.38	
Lesquerolic acid content (%)								
Mean ± S.E.	52.2 ± 0.5	53.8 ± 0.3	53.2 ± 0.1	53.4 ± 0.2	61.5 ± 2.2	54.8 ± 0.6	53.4 ± 0.2	53.1 ± 0.2
Range	47.7–56.5	52.3–55.3	52.3–54.0	51.7–54.6	57.8–65.4	40.0–67.8	53.0–53.8	50.4–55.4
C.V. (%)	4.2	2.0	0.9	1.4	6.2	7.4	0.0	2.5
t	2.71*		0.65		2.92**		0.96	
Lesquerolic acid yield (kg/ha)								
Mean ± S.E.			179 ± 10	194 ± 9			184 ± 45	165 ± 7
Range			117–264	118–246			129–273	90–300
C.V. (%)			24.0	18.6			42.1	28.6
t			1.07				0.43	

*,**,***Mean difference between populations measured by t-test (with 33 and 48 degrees of freedom for 1986 and 1988 populations) significant at $P=0.05$ and 0.01 and 0.001, respectively.

means of Subpopulation TX and AZ for all yield measurements within the two populations were tested by a t-test. Although there were some significant differences between the means of the two geographically distinct subpopulations, no consistent pattern indicated that one germplasm source was superior to the other. Subpopulation AZ, which apparently was derived from only one germplasm collection in Arizona, appears to have essentially the same range of variability as that of Subpopulation TX, which was derived from nine PI accessions collected at different locations in Texas.

Yield characteristics of progeny from six single plant selections are summarized and compared in Table 4. Valid statistical comparisons of yield performance can only be made among and between the HSFP and their TCP, which were grown in a replicated yield experiment in 1990–91. There were no statistically significant differences among the six HSFP for any of the six yield measurements. Statistically significant differences were measured for seed oil and lesquerolic acid contents among the six TCP, but these differences did not carry through to yield.

When the means of the six selected HSFP were compared with those of the six related TCP, no differences were measured for 1000-seed weight, seed oil and lesquerolic acid contents (Table 4). However, the TCP had significantly higher mean seed yields than the HSFP. The higher seed yields carried over into significantly higher yields of oil

TABLE 4

Yield characteristics of progenies from six single plant selections of *Lesquerella fendleri*

Yield measurements	Original population	Single plant selections	Half-sib families-1988	Half-sib family progency-1991	Topcross progency-1991
1000-seed weight (g)					
Mean ± S.E.	0.73 ± 0.04	0.82 ± 0.05	0.56 ± 0.02	0.61 ± 0.01[a]	0.60 ± 0.02[a]
Range	0.59–0.82	0.70–1.00	0.51–0.63	0.58–0.67	0.56–0.63
C.V. (%)	14.0	14.2	7.9	4.9	4.3
Seed yield (kg/ha)					
Mean ± S.E.			1876 ± 65	1373 ± 43[b]	1558 ± 35[a]
Range			1610–2044	1244–1527	1485–1717
C.V. (%)			8.4	7.7	5.6
Seed oil content (%)					
Mean ± S.E.	23.5 ± 1.1	27.1 ± 0.8	26.1 ± 0.9	29.2 ± 0.2[a]	29.1 ± 0.3[a]
Range	21.4–28.2	23.7–29.1	22.6–28.8	28.7–29.9	28.0–29.7
C.V. (%)	11.4	7.1	8.5	1.7	2.3
Seed oil yield (kg/ha)					
Mean ± S.E.			490 ± 27	401 ± 10[b]	453 ± 9[a]
Range			412–589	372–438	427–481
C.V. (%)			13.4	6.4	4.7
Lesquerolic acid content (%)					
Mean ± S.E.	54.8 ± 3.9	53.0 ± 3.4	52.3 ± 0.4	56.6 ± 0.2[a]	56.5 ± 0.7[a]
Range	38.4–64.7	40.0–61.4	51.0–53.4	56.1–57.1	54.6–58.8
C.V. (%)	17.5	15.6	1.7	0.8	3.2
Lesquerolic acid yield (kg/ha)					
Mean ± S.E.			256 ± 13	227 ± 6[b]	256 ± 8[a]
Range			217–300	214–248	233–281
C.V. (%)			12.0	6.0	7.5

[a]Mean separation in rows by Duncan's multiple range test, $P = 0.05$.

and lesquerolic acid exhibited by the TCP. As a group, the TCP also had significantly higher seed, oil and lesquerolic acid yields than the mean of the three bulk populations.

The increased seed yield of the topcrosses could well be a heterotic effect since lesquerella is normally cross pollinated. Inbreeding depression within the HSFP may account for a small part of the differences, but is not thought to be significant in this instance since the mating system utilized should not have significantly contributed to inbreeding. Male sterility has been observed within these populations at a relatively high frequency of about 15%. Research is under way to determine the genetic basis of the male sterility, and the possibility of using it to develop first-generation hybrid seed.

Conclusions

Clearly, the initial selection and breeding efforts summarized in this report, have resulted in some progress. However, efforts must be intensified if we are to achieve the objectives of full commercialization of lesquerella production. In general, the goal is to develop varieties or populations within five years that will produce 2000 kg/ha of seed containing 33.5% oil, which equates to an oil yield of about 670 kg/ha. It is anticipated that a US oil market of about 22 500 metric tons is attainable at a target product cost of about $0.75/kg for lesquerella oil. To meet this five year target, about 34 000 ha of production would be needed.

To reach these targets, an intensive breeding and genetic effort, coupled with the development of an

efficient crop production system, will be needed. These efforts are currently in progress. Agrigenetics L.P., a diversified developer, producer and marketer of planting seeds to worldwide agricultural markets, has launched an effort to develop proprietary varieties or populations to supply the projected demand for planting seed. Agrigenetic's initial germplasm source was from seeds of the S2 population provided by the USWCL. Their approach is to combine conventional plant breeding methods and applications of biotechnology to accelerate the process.

Continued focus of the USDA-ARS-USWCL, Phoenix, Arizona is primarily on germplasm collection, evaluation and enhancement. It is apparent from the data reported herein that a broader germplasm base is needed. To address this issue, an extensive, countrywide USDA-ARS germplasm collection effort, which will be phased over the next 3 or 4 years, has been funded and is being initiated in 1993. At present, only about one-third of the known species have been chemically evaluated and, in many instances, the species are only represented by one accession in our germplasm collection. The newly collected species will be chemically evaluated by the USDA-ARS-NCAUR, Peoria, Illinois.

A major germplasm development effort was initiated in 1992 at the USWCL to select favorable combinations of seed, seed oil and fatty acid yields. Over 500 single plant selections were made from a diverse germplasm base. Half-sib families of the top 10% of the selections are being evaluated in a replicated yield trial in 1993. Plans are being made to reselect and to develop a recurrent selection breeding population from the highest yielding selections.

Additionally, progeny of plants selected for autofertility are being evaluated for seed set under greenhouse conditions. Limited observations made in 1992 indicate that inadequate bee or other insect pollination may markedly reduce seed yields in large production fields. Continued cooperative experimentation is in progress with the USDA-ARS, Carl Hayden Bee Research Center, Tucson, Arizona to determine accurately the pollination requirements of lesquerella under field conditions. Determination of the nature of the male sterility, which has been observed in frequencies as high as 15% in pilot seed production populations, is also under investigation. This type of fundamental research is needed to support the rapid development of lesquerella as a new industrial oilseed crop.

Continued progress in increasing seed, oil and lesquerolic acid yields is anticipated to support the active, cooperative commercialization effort of industry, USDA, and state universities. It is concluded that the data presented in this paper will serve as a good bench mark upon which future progress in varietal and population development can be measured.

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